14th IEA Heat Pump Conference
15-18 May 2023, Chicago, Illinois

Free cooling in air conditioning: Investigation of its potential in Switzerland

Silvan Steiger[a], Christian Stahel[a]
Stefan Rohrer[a], Martin König[a], Frank Tillenkamp[a,*]

[a]Zurich Unviersity of Applied Sciences, Institute of Energy Systems and Fluid Engineering,
Technikumstrasse 9, 8400 Winterthur, Switzerland

Abstract

In air conditioning, free cooling is often used for saving energy. Free cooling is understood here as a bypass water circuit with direct recooling by the environment, not heat removal by nightly ventilation. Contrary to common practice in Switzerland, free cooling is not always economically beneficial. To estimate its potential in air conditioning systems, there are no generally applicable evaluation criteria or guidelines available. The aim of this work is to assess the free cooling potential in Switzerland by applying quasistatic simulations depending on supply temperature, application, location, circuit and type of heat discharge. The results show that supply temperature is the most influential parameter. Below 14 °C all investigated applications (except data centers) show generally less than 10% of free cooling amount in total annual cooling load, therefore not economically benefitting from it. Furthermore, the potential is strongly dependent on climate at the location. Cold regions like the Swiss alps allow longer yearly free cooling operation than warmer regions. If recoolers are used to pre-cool the returning cold water flow, the free cooling potential can almost be doubled.

Keywords: Free cooling; air conditioning; free cooling potential; Switzerland

1. Introduction

Free cooling (FC) is generally used in refrigeration systems for saving energy and reducing refrigeration costs. Recent literature also reflects this trend: Lot of successful effort is put into assessing the worldwide/european/swiss FC potential of data centers [1-3] and reviewing/optimizing existing FC systems in data centers [4-7]. This topic is of utmost importance considering the environmental impact of ever-increasing data traffic around the globe. Furthermore, it strongly improved expertise on how and where FC brings significant energy savings in data centers. Regarding FC potential for general air-conditioning applications, sophisticated work can be found addressing either the FC potential in specific cooling applications [8], [9], assessing it more generally at specific locations [10] or over a wider geographical scope [11]. As FC is a known technology by now, efforts are also put into expanding FC use, for example by applying phase change materials in combination with innovative cooling concepts [12-16]. As to FC potential in Switzerland, specific systems have been reviewed [17], [18]. Matthey and Affolter were able to determine the FC potential of the city of Neuchâtel [19], whereas Artmann, Manz and Heiselberg determined the FC potential by nightly ventilation over Europe [20]. This work aims to gain insight on FC potential in Switzerland with particular attention to influencing factors such as cold water supply temperature (T_{CWS}), application, location, hydraulic integration (circuit) and type of heat discharge.

* Corresponding author. Tel.: +41 58 934 73 61
E-mail address: frank.tillenkamp@zhaw.ch

2. Modelling

The analysis is intended to provide findings on appropriate use-cases for FC in air conditioning. For this purpose, applications in specific sample buildings were considered. With regard to modelling, they were all divided into three subsystems: recooler (refrigeration machine heat discharge), cold generation and cooling distribution/building (see Fig. 1**Error! Reference source not found.**). FC is assigned to the cold generation subsystem.

2.1. Parameter set

To assess influential variables on the FC potential, a suitable parameter set was established. It consists of varying values for the editable subsystems and boundary conditions: hydraulic integration (circuit), type of heat discharge, T_{CWS}, location with associated boundary conditions as well as type of cooling application.

Firstly, to clarify the influence of different hydraulic integrations, a total of five circuits (Fig. 1) were examined in consultation with experts. Each circuit contains the aforementioned subsystems and can be assigned to an operating group. Circuits 1, 2 and 4 are bivalent-alternative systems, where the cooling load is covered either by the refrigeration machine or FC. Circuits 3 and 5 are bivalent-parallel systems, whereby cold water can be precooled by FC and is simultaneously run with the refrigeration machine.

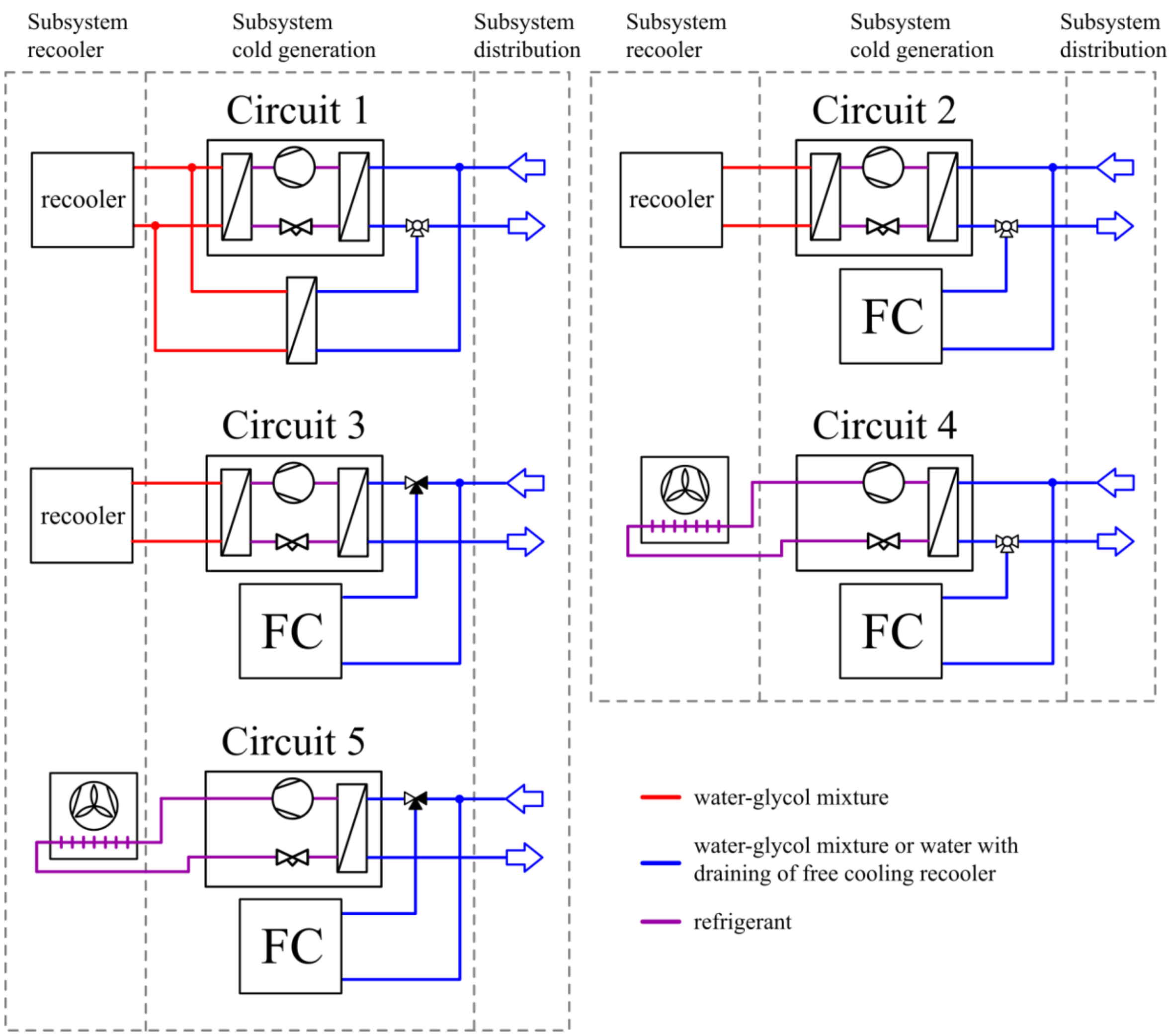

Fig. 1. Simplified scheme of investigated circuits

Secondly, various types of heat discharge systems were investigated. Depending on the type, FC return temperatures and therefore the possible FC operating time is affected. All types were simulated with a maximum capacity, which is never exceeded. This maximum capacity is defined as the design cooling load of the building, which was calculated site and application specific according to the standard of the Swiss Society of Engineers and Architects (SIA) 2024 [21]. In other words, separate discharge systems for FC (circuit 2 to 5) are able to dissipate the complete design load. The design also takes into account site-specific boundary conditions of the outside air (according to summer design data from SIA 2028 [22]) as well as application-specific sizes (according to SIA 2024 [21]). Every type leads to specific input parameters, which are summarized in Table 1. One value is the temperature difference between wet bulb and heat discharge return line (dT_{WB-RL}), which was assumed to be constant. The second value is the reference temperature (T_{ref}) at which heat can be discharged to.

Table 1: Details of investigated heat discharge systems for FC

Type of heat discharge	**Calculation dT_{WB-RL}**	**Calculation T_{Ref}**
Dry recooler	According to standard SWKI 2003-3 [23]	Location dependent outside air temperature according to standard SIA 2028 [22]
Hybrid recooler	According to standard SWKI 2003-3 [23]	Location dependent wet bulb temperature according to standard SIA 2028 [22]
Geothermal probe	According to standard SIA 384/6 [24]	Location dependent soil temperature according to standard SIA 384/6 [24]
Groundwater collection	Mean of values to strive for according to VDMA 24247-8 [25]	Location dependent wet bulb temperature according to standard SIA 2028 [22]

Some simplifications and delimitations must be considered: Hybrid recoolers were modeled to be sprayed on with water constantly, leading to the maximum possible FC potential. In every simulation run, the used heat discharge system (dry/hybrid) of the refrigeration machine was the same as for FC. Regarding geothermal probes and groundwater collection, soil temperature changes as well as legal regulations were neglected, also resulting in maximum FC potential. Ground temperature could only be estimated and varies strongly with subsurface conditions and drilling depth, only allowing a rough estimation of FC potential. For circuits 2 to 5, separate FC with geothermal probes or groundwater is excluded. Usually, those heat discharge systems are built for recooling the refrigeration machine and are additionally used for FC, which reduces circuits 2 to 5 to circuit 1 in this regard. The effect of water fed heat discharge systems was therefore only calculated with circuit 1.

Thirdly, T_{CWS} was varied to investigate its influence. By choosing the temperature level of the cold water, that for FC is also determined which in turn affects its possible operating time. According to SIA 382/1 [26], temperatures of 6, 10 and 14 °C were used representing typical values for air conditioning applications. 18 °C serves as an interpolation value and with 22 °C a typical temperature for data center cooling was included. T_{CWS} is always assumed to be constant, hence no adjustment to the outside temperature is considered.

Fourth, different locations were evaluated. Due to various environmental conditions, the heating and cooling demand of an application as well as the minimum temperature of heat discharge are affected. To evaluate the site dependency, data of the weather measuring stations Zurich, Basel, Geneva, Lugano and Davos were included (Fig. 2). These can be assigned to one of the three climatic/geographical regions of Switzerland: Central plateau, Swiss alps and Ticino (Table 2). This assignation serves to extrapolate to a more general view over Switzerland. Weather data was obtained from the Federal Office of Meteorology and Climatology (MeteoSwiss) [27]. In the years 2010 to 2016, the year 2013 shows the smallest deviation of annual mean values from the norm across all stations considered (according to MeteoSwiss). Therefore, 2013 was finally used for weather data. Table 3 shows weather parameters (measured in hourly mean values) used for the calculation.

Table 2: Locations and their boundary conditions

Region	**Location**	**Meters above sea level**	**Annual mean air temperature $T_{0,a}$ [°C]**	**Annual mean soil temperature [°C]**
Central plateau	Basel	316	10.3	12.4
	Geneva	410	10.2	12.6
	Zurich	426	9.4	11.3
Swiss alps	Davos	1594	3.6	7.2

2.8	14.4

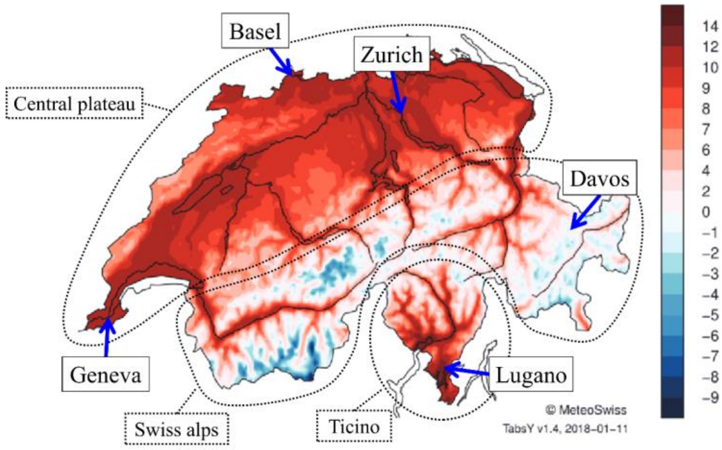

Fig. 2: Annual mean temperature map of Switzerland with marked climatic/geographical regions and locations of used weather data stations [29].

Table 3: Used weather data (hourly values)

Value	**Unit**
Air temperature 2 m above ground	°C
Wet bulb temperature 2 m above ground	°C
Air pressure at station height	hPa
Relative humidity 2 m above ground	%
Global irradiation	W/m^2

Fifth, different proportions of internal heat were evaluated by including different types of applications according to standard SIA 2024 [21]. As Table 4 shows, the selection was based on the widest possible spread of internal heat load share.

Table 4: Investigated types of application

Type of application	**Designation according to SIA 2024** [21]	**Proportion of internal heat load to total heat load [%]**
Hospital/doctors office	Treatment rooms	51
Office building	Open-plan office	57
Department store	Specialty store, department store	83
Data center	Server room	99

2.2. Calculation Model

The applied calculation model is based on thermal energy balances of hourly intervals over a calendar year. This leads to a quasi-static view of the system, which means that storage effects of the building mass and in possible cold or heat storages are not considered. As depicted in Eq. (1), the hourly target thermal load of a building was calculated according to the standard SIA 2024 [21].

$$Q_{dem} = (\Phi_T + \Phi_v + \Phi_i + \Phi_s) \cdot A_{NFA} \tag{1}$$

$$Q_{dem} \leq 0 \quad \Rightarrow \quad Q_{dem,C} = Q_{dem} \tag{2}$$

$$Q_{dem} \geq 0 \quad \Rightarrow \quad Q_{dem,H} = Q_{dem} \tag{3}$$

Here, Q_{dem} is the hourly heating/cooling demand, Φ is the specific heating/cooling load with indexes T for transmission, v for ventilation, i for internal and s for solar load. A_{NFA} is the net floor area of the representative building. If the target thermal load is negative, cooling load is present (Eq. (2)) and if it results positive, heat load exists (Eq. (3)). Specific heating/cooling loads were calculated according to the standards SIA 2024 [21] and SIA 2028 [22]. Further information on the calculation can be found in [28].

2.3. Evaluated quantitites

The value of greatest interest is the FC potential, as shown in Eq. (4). It is intended to provide information on the usefulness of FC in relation to the total cooling load. For this purpose, the yearly amount of discharged heat by FC ($\sum Q_{C,FC,a}$) was compared with the yearly total cooling load ($\sum Q_{C,tot,a}$) for each parameter combination.

$$FC\ potential = \frac{\sum Q_{C,FC,a}}{\sum Q_{C,tot,a}} \cdot 100\% \qquad (4)$$

In order to provide assistance to the reader, a calculation of the economic efficiency for a 200 kW refrigeration plant was carried out [28]. To keep annual costs of a system with FC at the same level as a conventional one, a FC potential of at least 11% (best case) or 39% (worst case) must be achieved. Otherwise, FC is not considered economically viable. This classification is listed consistently in the results (cf. section 3).

3. Results

A total of 1200 parameter combinations were simulated and evaluated using the procedure described in section 2. The most important findings are outlined below.

3.1. Influence of cold water supply temperature

Out of all parameters T_{CWS} has the most significant influence on FC potential. As an example, the evaluation for Zurich (representing the central plateau region) with dry recooler heat discharge is displayed in Fig. 3. It shows that the FC potential decreases with decreasing T_{CWS}. At $T_{CWS} < 10\,°C$, the FC potential drops below 2 % for all circuits and applications, except the data center. This tendency applies to all locations, heat discharge types, applications and circuits [28]. Applications with a low proportion of internal heat loads (hospital/doctors office, office buildings) show the strongest response to this tendency.

The data center application represents a special case: Due to year-round cooling load, a considerable proportion can be served by FC, even with relatively low T_{CWS}. This confirms the common use of FC in data

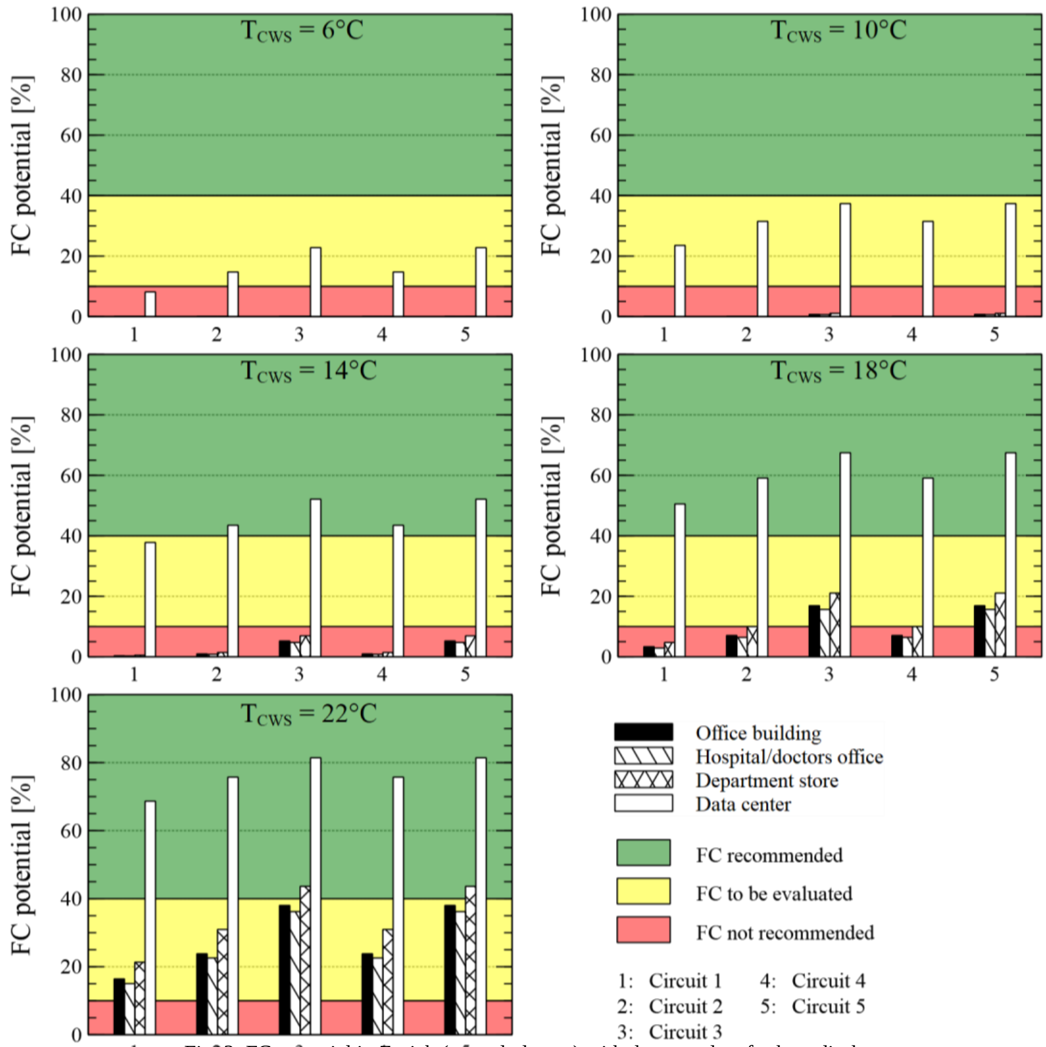

Fig. 3: FC potential in Zurich (central plateau) with dry recoolers for heat discharge.

center chiller systems. However, it stresses the crucial point that cooling with high T_{CWS} leads to great FC potential (up to 81 % in this evaluation) and therefore high energy savings.

3.2. Influence of hydraulic integration (circuit)

The FC potential is further influenced by the choice of hydraulic integration. The evaluation for Zurich with dry recooler heat discharge (cf. Fig. 3) serves as an example again. Across all locations, heat discharge types, applications and T_{CWS}, three main influences of the circuit can be identified:

Temperature difference across heat exchangers

Large temperature differences across heat exchangers have a negative influence on the FC potential since they reduce the necessary spread between T_{CWS} and the return temperature of the FC. Parameter combinations with circuit 1 (largest temperature differences over the heat exchangers) therefore generally have the lowest FC potential.

Operating mode of FC

The operating mode of FC has an influence on the performance, independent of all other parameters. With bivalent-parallel mode the cold water return flow can be precooled as soon as the return temperature of the heat discharge is lower. This allows longer FC operating periods and consequently higher FC potentials. It can be seen that bivalent-parallel systems generally have higher FC potential than bivalent-alternative ones (compare results of circuits 2 & 3 as well as those of circuits 4 & 5).

Type of refrigeration machine condenser

Comparing circuits 2 & 4 as well as circuits 3 & 5, they differ only in the type of refrigeration machine condensation (cf. Fig. 1). No influence on the FC potential can be determined. Circuits which only differ by direct or indirect condensation show the same FC potential for identical parameter combinations.

3.3. Influence of location

The location defines $T_{0,a}$, which influences both T_{Ref} and the application's heat load profile, which in turn significantly influences the FC potential across all parameter combinations. The decisive factor for this influence is the dependence of the heat discharge system return temperature on the outside air temperature.

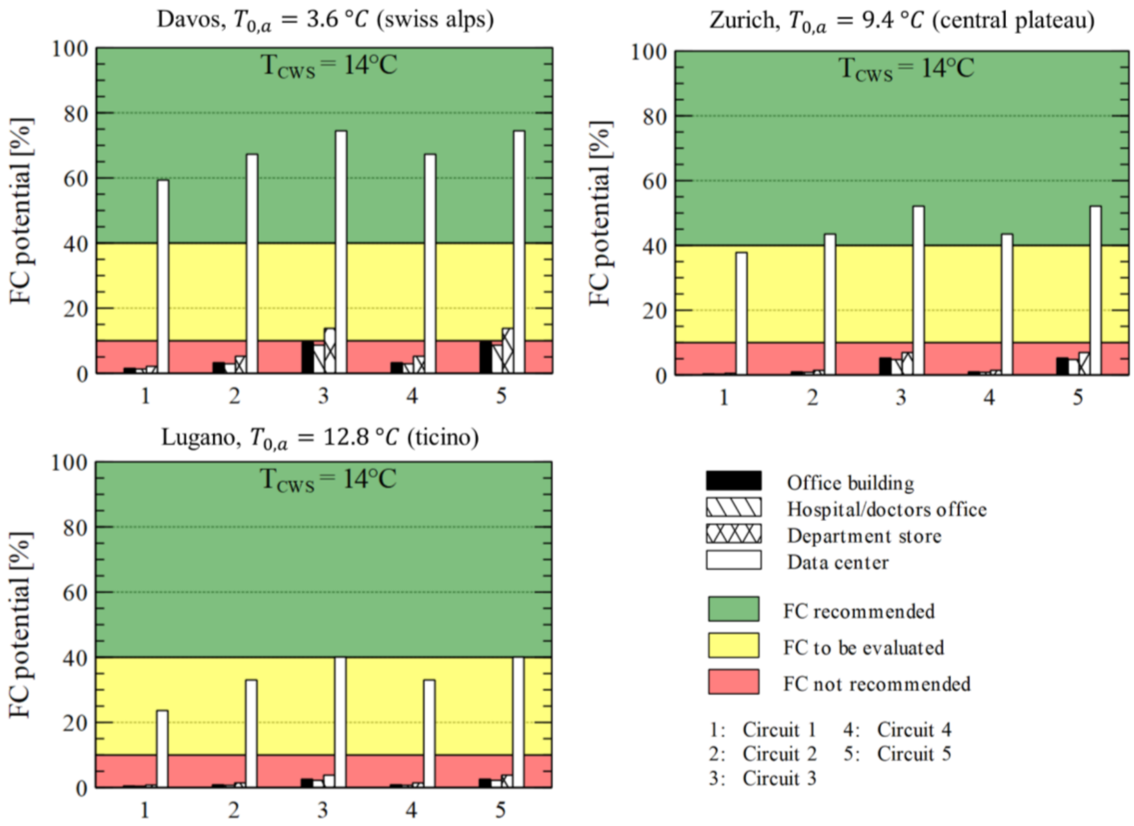

Fig. 4: FC potential for different locations with dry recoolers for heat discharge.

As an example, the FC potential evaluation with dry recooler heat discharge and $T_{CWS} = 14\,°C$ for different regions is shown in Fig. 4. Regardless of the remaining parameters, it can be determined that low ambient temperatures increase the FC potential. Thus, with the same application and circuit, greater potential can be achieved in the Swiss alpine region rather than the Central plateau or Ticino. All investigated locations in the Central plateau show only minor FC potential changes to Zurich.

3.4. Influence of heat discharge system

<u>Dry recooler vs. hybrid recooler</u>

As an example, the evaluation of FC potential at $T_{CWS} = 14\ °C$ and $T_{CWS} = 22\ °C$ for Zurich is shown in Fig. 5. It must be considered that the hybrid recooler was modeled as if it were constantly sprayed on with water. Therefore, the results for hybrid recooling show the maximum possible FC potential. With hybrid recooling, the FC potential can be greatly increased compared to dry recooling. In some cases, it can be even more than doubled.

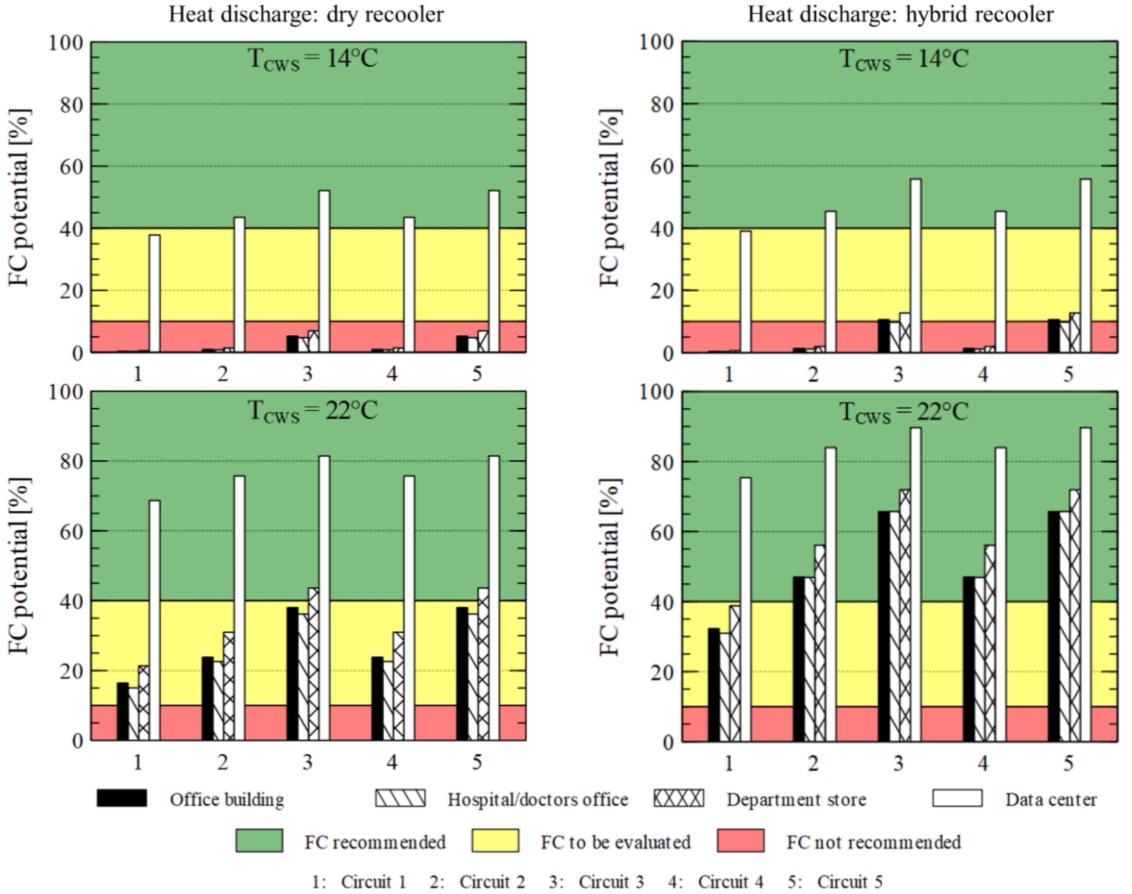

Fig. 5: FC potential for dry and hybrid recooler heat discharge in Zurich.

<u>Geothermal probes and groundwater collection</u>

Due to the simplifications made (cf. section 2.1), only an estimation of the maximum FC potential of geothermal probes and groundwater is possible. Reminder: In order to determine the effects of water-fed heat discharge systems, only circuit 1 was simulated.

The evaluations (Fig. 6) show a large FC potential at high T_{CWS} over all investigated locations. In generally cold regions such as the Swiss alps (Davos), FC by groundwater collection can also be useful with low T_{CWS} due to lower soil temperatures. It should be noted that heat discharge may be limited by legal restrictions. A more exact statement would require a further investigation, in which the dynamic behavior of the geothermal probe as well as groundwater collection is analyzed under consideration of the heat inputs.

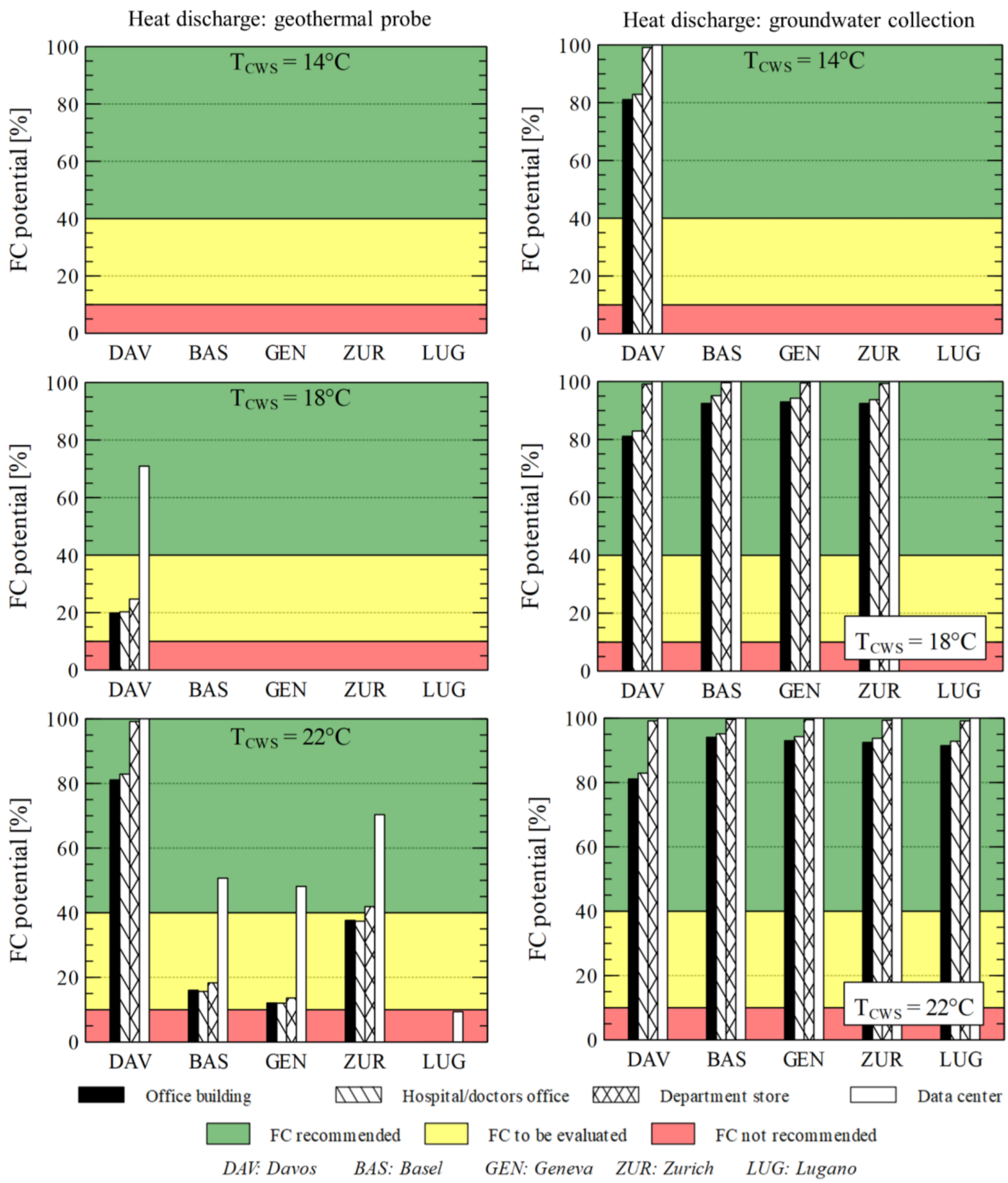

Fig. 6: FC potential with geothermal probes and groundwater collection for circuit 1.

4. Conclusion and Outlook

The main objective of the present study was to investigate the FC potential in Switzerland. This was done by applying quasistatic simulations on typical FC use-cases for different T_{CWS}, applications, locations, circuits, and types of heat discharge. A total of 1200 parameter combinations were calculated where 700 cases (58.3 %) belong into the category "FC not recommended", with FC potential under 11 %. Another 280 cases (23.3 %) belong to the category "FC to be evaluated", with FC potential between 11 % and 39 %. These cases can economically benefit from FC, depending on the exact operating conditions. Last but not least, 220 cases (18.3 %) belong to the category "FC recommended" with FC potential over 39 %. This means that, according to this assessment, only less than half of all parameter combinations considered have a potential for which FC should be evaluated or for which it is recommended. However, it should be noted here: Not all investigated parameter combinations make practical sense (e.g., data centers usually aren't cooled with $T_{CWS} = 6\ °C$). Nevertheless, this study reveals important principles for the use of FC, which are summarized below.

1) Cooling and FC should be carried out at the highest possible T_{CWS}. This increases the FC potential on one hand and the general energy savings on the other.
2) Regarding hydraulic integration (circuit), the difference between direct and indirect condensation of the refrigeration machine is negligible. Bivalent-parallel systems with precooling the cold water return flow generally show higher FC potential than bivalent-alternative systems.
3) In terms of used heat discharge systems, hybrid recoolers or geothermal probes/groundwater collections show large improvements in FC potential in some cases. Especially at high T_{CWS}, water fed heat discharge systems show great advantages.

The analysis of the data center even allows to transfer some conclusions of the results onto industrial refrigeration applications. If it is assumed that an industrial application has a year-round cooling demand, increased FC potential can be expected. If, in addition, high T_{CWS} are present the FC potential can be maximized. From this point of view, FC is a very interesting technology for certain industrial cooling applications. However, the exact relationships would have to be investigated in more detail. In addition, it must not be forgotten for industrial refrigeration applications, that a possible heat utilization is clearly preferable to a heat release to the environment. With the results in this study, it is possible to estimate the FC potential for a specific cooling system. For this purpose, various diagrams and a description of the procedure are provided in the original research report [28]. Furthermore, detailed analyses can also be found there.

With the Swiss Federal Office of Energy as contracting authority, this study was limited to investigations in Switzerland. Further studies for regions with warmer or colder climates than Switzerland can provide information on the validity of this approach as well as further insights on the FC potential in those regions.

Acknowledgements

The Authors would like to thank the Swiss Federal Office of Energy for their financial support in this project. Mr. Martin Stettler is expressly thanked. Thanks for the valuable support and constructive cooperation also go to the contributing experts Arnold Brunner (Brunner Consulting), Robert Dumortier, Michael Kriegers (Meierhans und Partner) and Thomas Lang (zweiweg GmbH). For further technical support we would also like to thank Luk End and Matthias Brügger (Leplan AG).

Nomenclature and Abbreviations

A_{NFA}	Net floor area of representative building	FC	Free cooling
$T_{0,a}$	Annual mean air temperature	MeteoSwiss	Swiss Federal Office of Meteorology and Climatology
T_{CWS}	Temperature of cold water supply line	SIA	Swiss society of engineers and architects
$dT_{WB\text{-}RL}$	Temperature difference between wet bulb and heat discharge return line	SWKI	Swiss association of building services engineers
T_{ref}	Temperature, at which heat can be discharged to (depending on heat discharge system)	VDMA	German mechanical engineering industry association
$\sum Q_{C,FC,a}$	Yearly amount of dircharged heat by free cooling	$\sum Q_{C,tot,a}$	Yearly total cooling load

References

[1] K. P. Lee and H. L. Chen, "Analysis of energy saving potential of air-side free cooling for data centers in worldwide climate zones," *Energy Build*, vol. 64, pp. 103–112, 2013, doi: 10.1016/j.enbuild.2013.04.013.

[2] T. Malkamäki and S. J. Ovaska, "Solar energy and free cooling potential in European data centers," in *Procedia Computer Science*, 2012, vol. 10, pp. 1004–1009. doi: 10.1016/j.procs.2012.06.138.

[3] A. Altenburger, "Energieeffizientes Kühlen von IT-Räumen," 2004. [Online]. Available: www.electricity-research.ch

[4] Y. Yang, B. Wang, and Q. Zhou, "Air Conditioning System Design using Free Cooling Technology

and Running Mode of a Data Center in Jinan," in *Procedia Engineering*, 2017, vol. 205, pp. 3545–3549. doi: 10.1016/j.proeng.2017.09.924.

[5] Y. Udagawa, S. Waragai, M. Yanagi, and W. Fukumitsu, "Study on free cooling systems for data centers in Japan," in *INTELEC, International Telecommunications Energy Conference (Proceedings)*, 2010. doi: 10.1109/INTLEC.2010.5525676.

[6] H. Zhang, S. Shao, H. Xu, H. Zou, and C. Tian, "Free cooling of data centers: A review," *Renewable and Sustainable Energy Reviews*, vol. 35. Elsevier Ltd, pp. 171–182, 2014. doi: 10.1016/j.rser.2014.04.017.

[7] J. Ni and X. Bai, "A review of air conditioning energy performance in data centers," *Renewable and Sustainable Energy Reviews*, vol. 67. Elsevier Ltd, pp. 625–640, Jan. 01, 2017. doi: 10.1016/j.rser.2016.09.050.

[8] U. Berardi, G. Heidarinejad, S. Rayegan, and H. Pasdarshahri, "Enhancing the cooling potential of a solar-assisted desiccant cooling system by ground source free cooling," *Build Simul*, vol. 13, no. 5, pp. 1125–1144, Oct. 2020, doi: 10.1007/s12273-020-0696-0.

[9] B. Li, P. Wild, and A. Rowe, "Free cooling potential of air economizer in residential houses in Canada," *Build Environ*, vol. 167, Jan. 2020, doi: 10.1016/j.buildenv.2019.106460.

[10] H. Bulut and M. A. Aktacir, "Determination of free cooling potential: A case study for İstanbul, Turkey," *Appl Energy*, vol. 88, no. 3, pp. 680–689, 2011, doi: 10.1016/j.apenergy.2010.08.030.

[11] C. Ghiaus and F. Allard, "Potential for free-cooling by ventilation," *Solar Energy*, vol. 80, no. 4, pp. 402–413, Apr. 2006, doi: 10.1016/j.solener.2005.05.019.

[12] A. Maccarini, G. Hultmark, N. C. Bergsøe, and A. Afshari, "Free cooling potential of a PCM-based heat exchanger coupled with a novel HVAC system for simultaneous heating and cooling of buildings," *Sustain Cities Soc*, vol. 42, pp. 384–395, Oct. 2018, doi: 10.1016/j.scs.2018.06.016.

[13] A. Waqas and Z. Ud Din, "Phase change material (PCM) storage for free cooling of buildings - A review," *Renewable and Sustainable Energy Reviews*, vol. 18. pp. 607–625, 2013. doi: 10.1016/j.rser.2012.10.034.

[14] S. A. Nada, W. G. Alshaer, and R. M. Saleh, "Experimental investigation of PCM transient performance in free cooling of the fresh air of air conditioning systems," *Journal of Building Engineering*, vol. 29, May 2020, doi: 10.1016/j.jobe.2019.101153.

[15] K. Panchabikesan, A. A. R. Vincent, Y. Ding, and V. Ramalingam, "Enhancement in free cooling potential through PCM based storage system integrated with direct evaporative cooling (DEC) unit," *Energy*, vol. 144, pp. 443–455, Feb. 2018, doi: 10.1016/j.energy.2017.11.117.

[16] V. A. A. Raj and R. Velraj, "Review on free cooling of buildings using phase change materials," *Renewable and Sustainable Energy Reviews*, vol. 14, no. 9. Elsevier Ltd, 2010. doi: 10.1016/j.rser.2010.07.004.

[17] M. Mosteiro-Romero, E. Riegelbauer, S. Hsieh, and A. Schlueter, "District-scale lake water free cooling in Zurich, Switzerland: System performance simulation and techno-economic feasibility," *Proceedings of ECOS 2020*, 2020, doi: 10.3929/ethz-b-000426953.

[18] M. Eberhard, "Erdwärmesondenfeld Aarau," Aarau, 2005.

[19] B. Matthey and M. Affolter, "Freecooling en milieu urbain," 2009.

[20] N. Artmann, H. Manz, and P. Heiselberg, "Passive cooling of buildings by night-time ventilation," 2008. [Online]. Available: www.empa.ch

[21] Swiss society of engineers and architects SIA, "SIA 2024: Standard-Nutzungsbedingungen für die Energie-und Gebäudetechnik." Zurich, 2006.

[22] Swiss society of engineers and architects SIA, "SIA 2028: Klimadaten für Bauphysik, Energie - und Gebäudetechnik." Zurich, 2008.

[23] Swiss association of building services engineers SWKI, "SWKI 2003-3:2005 Rückkühlung." Schönbühl, 2005.

[24] Swiss society of engineers and architects SIA, "SIA 384/6: Erdwärmesonden." Zurich, 2010.

[25] German mechanical engineering industry association VDMA, "VDMA 24247: Energieeffizienz von Kälteanlagen, Teil 8: Komponenten - Wärmeübertrager," 2011.

[26] Swiss society of engineers and architects, "SIA 382/1: Lüftungs- und Klimaanlagen - Allgemeine Grundlagen und Anforderungen." Zurich, 2014.

[27] Federal Office of Meteorology and Climatology MeteoSwiss, "Measurement values." https://www.meteoswiss.admin.ch/home/measurement-values.html?param=messwerte-lufttemperatur-10min (accessed Nov. 11, 2022).

[28] S. Rohrer, M. König, and F. Tillenkamp, "Free Cooling in der Klimakälte Untersuchung des Potentials in der Schweiz," *IEFE Energy Papers*, vol. 7, no. 1, 2018, doi: 10.21256/zhaw-1369.

[29] Federal Office of Meteorology and Climatology MeteoSwiss, "Klimabulletin Jahr 2017." Zurich, 2018.